भारतीय मानक

Indian Standard

IS 18315 : 2023

# चक्रवाती कारक ($k_4$) अनुमान — दिशानिर्देश

# Estimation of Cyclonic Factor ($k_4$) — Guidelines

ICS 91.120.99

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**August 2023** **Price Group 6**

Cyclone Resistant Structures Sectional Committee, CED 57

## FOREWORD

This Indian Standard was adopted by the Bureau of Indian Standards, after the draft finalized by the Cyclone Resistant Structures Sectional Committee had been approved by the Civil Engineering Division Council.

India has many urban and suburban regions that are located in coastal areas. It is surrounded on the eastern side by the Bay of Bengal, at its bottom by the Indian ocean, and on the western side, it is surrounded by the Arabian sea. Cyclonic storms form far away from the sea coast and gradually reduce speed as they approach the seacoast. Cyclonic storms generally extend up to about 60 km after striking the coast. The frequency of cyclonic storms is more along the east coast as compared to the west coast of India. The coastal regions of the states of Tamil Nadu, Andhra Pradesh, Orissa and West Bengal on the east coast and Gujarat on the west coast are cyclone prone.

Cyclones associated with high speed winds followed by heavy rains and accompanied by surges have been causing untold misery to the populace and widespread devastation of properties in the coastal belts of India. In extreme wind conditions, the force of the oncoming flow may lead to rupture damage in buildings and structures. The statistics of the types of damage clearly indicate that even today, many structures and structural components are not sufficiently wind hazard resistant. Therefore, improvements are required in the design methodologies to ensure greater structural safety, particularly in respect of life-line structures involved in relief and rehabilitation, and those whose failure has significant financial implications

Due to this, a need has been felt to research at the national level with the updated cyclone data. In view of that, an R&D project was awarded to the Indian Institute of Technology (BHU), Varanasi, funded by the Bureau of Indian Standards, based on which, these guidelines for estimating the cyclonic factor ($k_4$) have been prepared. The guidelines given in this standard are intended to reduce the damage to buildings and structures (particularly those mentioned in the foregoing paragraph) in the event of a cyclone through better estimation of forces.

The cyclonic factor given in IS 15498 : 2004 'Guidelines for improving the cyclonic resistance of low rise houses and other buildings/structures' was based on the research conducted at CSIR — Structural Engineering Research Centre (CSIR-SERC), Chennai with consideration of 3 min cyclonic wind speed data from year 1969 to 1985. In the present research, wind speed data during cyclonic hours have been considered from 1982 to 2020.

The threshold speed considered by the CSIR-SERC was 62 knot (31.9 m/s), however in this research the threshold speed considered is 65 knot (33.4 m/s). In view of the structural failures observed during the previous cyclones it was decided to consider the higher threshold speed. The threshold speed is the minimum speed at structure or building is likely to be damaged. This R&D project with much larger observation period of cyclonic data and revised threshold speed found the results in line with the previously carried out research at CSIR-SERC.

'Enhancement factor for the cyclonic region' as per IS 15498 : 2004 or 'Importance factor for the cyclonic region' as per IS 875 (Part 3) : 2015 'Design loads (other than earthquake) for buildings and structures — Code of practice: Part 3 Wind loads (*third revision*)' are generally referred as cyclonic factor ($k_4$).

The factor obtained for enhancement of design wind speed for the cyclonic region is being termed as cyclonic factor ($k_4$). Annex A demonstrates on the basis of two major international standards that they all recognise the need to use higher design values for cyclonic regions, but may adopt different approaches or computational algorithms for calculating the same.

In the formulation of this standard, assistance has been derived from the following publications:

a) AS/NZS 1170.2 : 2021 'Structural design actions: Part 2 Wind actions'
b) ASCE (7-16) : 2017 'Minimum design loads and associated criteria for buildings and other structures'

(*Continued on third cover*)

*Indian Standard*

# ESTIMATION OF CYCLONIC FACTOR ($k_4$) — GUIDELINES

## 1 SCOPE

This standard covers the guidelines for estimation of cyclonic factor ($k_4$).

## 2 REFERENCES

The standards given below contain provisions which, through reference in this text, constitute provisions of this standard. At the time of publication, the edition indicated were valid. All standards are subject to revision, and parties to agreements based on this standard are encouraged to investigate the possibility of applying the most recent edition of these standards:

| *IS No.* | *Title* |
|---|---|
| IS 875 (Part 3) : 2015 | Design loads (other than earthquake) for buildings and structures — Code of practice: Part 3 Wind loads (*third revision*) |
| IS 15498 : 2023 | Guidelines for improving the cyclonic resistance of low rise houses and other buildings |

## 3 TERMINOLOGY

For the purpose of this standard, the following definitions and those given in IS 875 (Part 3) shall apply.

**3.1 Threshold Speed** — The minimum speed at which a structure or building is likely to be damaged. The recommended threshold speed for estimation of cyclonic factor is 33.4 m/s (65 knot).

## 4 CYCLONIC WIND FIELD

Cyclones are vortices in the atmosphere having a core called the eye of extremely low pressure and light winds, surrounded by strong winds having nearly circular contours of equal pressure called isobars. The circulatory system is in the anti-clockwise direction in the northern hemisphere. The radial distance from the centre of the eye to the region where the maximum tangential wind velocity occurs is called the radius of maximum winds (RMW). The wind speed falls off gradually beyond this region, and the approximate wind velocity distribution is given as:

$$V(r) = V_0 \left(\frac{r_0}{r}\right)^{\alpha} \qquad \dots (1)$$

where

$V(r)$ = velocity of wind at a radial distance, $r$;

$V_0$ = velocity of maximum wind;

$r_0$ = radius of maximum wind (RMW); and

$\alpha$ = a power law exponent varying between 0.4 to 0.6.

NOTE — $r$ and $r_0$ are to be measured from the centre of the eye of the storm. In the interior region to the radius of maximum wind, the velocity distribution may be assumed as linear by varying from zero at centre of eye.

## 5 CYCLONIC FACTOR ($k_4$) FOR DESIGN OF BUILDINGS AND STRUCTURES

**5.1** It is known that higher wind speed occurs during cyclones compared to non-cyclonic storms. Further, there is a greater degree of turbulence in such storms. Therefore, structures are subjected to greater risk under cyclonic storms. The basic wind speed recommended by IS 875 (Part 3) is 50 m/s for cyclonic regions. However, it is observed that the eastern coast of India also experienced some super cyclones with wind speeds significantly higher than the basic wind speed of 50 m/s. In view of that a cyclonic factor ($k_4$), has been introduced to determine the design wind speed.

**5.2** Cyclonic factor ($k_4$) only accounts for increased cyclonic wind speed over and above non-cyclonic speed specified in the basic wind speed map. Cyclonic factor ($k_4$) is always applied to a reference basic wind speed of 50 m/s for the coastal region, which corresponds to return period of 50 years and a load factor of 1.5. IS 15498 suggests the cyclonic factor for industrial structures and life line structures which are involved in emergency services, relief and rehabilitation in the event of a cyclonic event (such as cyclone shelters, hospitals, schools, communication towers, water towers, transportation links etc). The cyclonic factors for different buildings and structures at the threshold wind speed of 33.4 m/s are calculated as given in Table 1.

**5.3** Gumbel distribution has been found to be the best for modelling cyclonic wind speeds. Accordingly, cyclonic factor ($k_4$), is defined as the ratio of the 3 s gust cyclonic wind speed (with $N$ years of mean probable design life) to the 3 s gust non-cyclonic wind speed (with 50 years of mean probable design life). Durst curve with conversion factor of 1.2 is used for converting the 3 min wind speed to 3 s gust wind speed. Equation for determining the cyclonic factor for different return periods is given below:

$$k_4 = \frac{X_{\mathrm{N},\ \mathrm{P_N}}\ \text{(3 s gust cyclonic wind speed)}}{X_{50,\,0.63}\ \text{(3 s gust non} - \text{cyclonic wind speed)}}$$

$$k_4 = \frac{X_{\mathrm{N,\,PN}}}{X_{50,\ 0.63}} = \frac{\frac{\sigma*\sqrt{6}}{\pi}\left\{-\,0.577\,2 - \left[\mathrm{In}\left\{-\frac{1}{N}\mathrm{In}\,(1 - P_{\mathrm{N}}\}\right)\right]\right\} + m}{\mathrm{A} + 4\mathrm{B}} \qquad \dots (2)$$

where

$X_{\mathrm{N,\,PN}}$ = extreme wind speed in m/s for $N$ years of mean probable design life of the structure with exceedance probability, $P_{\mathrm{N}}$;

$N$ = mean probable design life of structure in years;

$\mathrm{P_N}$ exceedance probability for $N$ years = $[1 - (1 - 1/N)^N]$;

$X_{50,\ 0.63}$ = extreme wind speed in m/s for 50 years of mean probable design life of the structure with exceedance probability ($P_N$) of 0.63 (*see* Note 1);

$\sigma$ = standard deviation obtained from Gumbel distribution,

$m$ = mean obtained from Gumbel distribution; and

A and B = constant as given in IS 875 (Part 3) for basic wind speed 50 m/s (*see* Note 2).

NOTES

**1** For a return period of 50 years exceedance probability, $P_{\mathrm{N}} = 1 - \left(1 - \frac{1}{50}\right)^{50} \sim 0.63$.

**2** For 50 m/s, A = 24.67 m/s and B = 6.34 m/s as per IS 875 (Part 3). The value of the denominator A + 4B = 50 m/s.

**3** For standard deviation and mean, *see* Annex B.

### Table 1 Cyclonic Factor for Different Structures

(*Clause* 5.2)

| **Probability Distribution** | **3 min Wind Speed** ($x_{3\ \mathrm{min}}$) m/s | **3 s Gust Wind Speed with Load Factor = 1** ($x_{3\ \mathrm{s}} = x_{3\ \mathrm{min}} \times 1.2$) m/s | **3 s Gust Wind Speed with Load Factor = 1.5** $= \frac{x_{3\ \mathrm{s}}}{(1.5)^{0.5}}$ m/s | **Cyclonic Factor ($k_4$) as per Eq 2** | | |
|---|---|---|---|---|---|---|
| | | | | All other structures | Industrial Structures | Life-line Structures such as Cyclonic Shelters, Hospitals and Transmission Line Towers, Water towers,Transportation links |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) |
| Gumbel | 65.42 | 65.42 × 1.2<br>= 78.50 | $78.50/(1.5)^{0.5}$<br>= 64.09 | 1 | 1.14 | 1.28 |

## ANNEX A

(*Foreword*)

## COMPARISON WITH OTHER INTERNATIONAL STANDARDS

### A-1 COMPARISON OF CYCLONIC FACTOR AS PER INDIAN STANDARD

In order to ensure greater safety in the cyclonic regions, IS 875 (Part 3) introduced a cyclonic factor ($k_4$) in the determination of the design wind speed of the structure in addition to the existing probability factor or risk factor. The following values of $k_4$ are rendered according to the importance of the structure in the context of its utility as a life-line structure or the economic impact due to its failure. In the previous study, the threshold speed was considered 62 knot (31.9 m/s), however in this study, the threshold speed considered is 65 knots (33.4 m/s), as in view of the structural failures observed during the previous cyclones it was decided to consider the higher threshold speed. Table 2 shows the comparison of the cyclonic factor with different threshold speed.

### A-2 COMPARISON WITH OTHER INTERNATIONAL STANDARDS

The following sections demonstrate that the need to use higher design values for cyclonic regions is well recognised, but different approaches, categorisations or computational algorithms for calculating the same may be adopted.

### A-2.1 Comparison with AS/NZS 1170.2 : 2021 ‘Structural design actions: Part 2 Wind actions’

Based on occupancy and use, the Australian/New Zealand standard divided the structures and buildings into five danger classes. Normal structures, such as homes and businesses, are classed as importance levels 2 or 3, and post-disaster structures, such as schools and hospitals, are classified as importance level 4. Table 3 shows the consequences of failure for importance levels.

**Table 2 Comparison of Cyclonic Factor as per Indian Standard**

(*Clause* A-1)

| Sl No.<br>(1) | Structures<br>(2) | With the Threshold Value of 31.8 m/s (62 knot)<br>(3) | With the Threshold Value of 33.4 m/s (65 knot)<br>(4) |
|---|---|---|---|
| i) | Post-cyclone important structures (Life-line structures) | 1.3 | 1.28 |
| ii) | Industrial structures | 1.15 | 1.14 |
| iii) | All other structures | 1.00 | 1.00 |

**Table 3 Consequence of Failure for Importance Levels (AS/NZS 1170.2 : 2021)**

(*Clause* A-2.1)

| Sl No.<br>(1) | Consequence of Failure<br>(2) | Description<br>(3) | Importance Levels<br>(4) | Comment<br>(5) |
|---|---|---|---|---|
| i) | Low | Low consequence | 1 | Minor buildings (failure not likely to affect human life) |
| ii) | Ordinary | Medium consequence | 2 | Normal structures |
| iii) | High | High consequence | 3<br>4 | Major buildings (affecting crowds)<br>Post-disaster installations |
| iv) | Exceptional | Circumstances where reliability must be set on a case by case basis | 5 | Exceptional structures |

The definition 'post-disaster installations' (level 4) and 'normal structures' (level 2) as per Table 3, from AS/NZS 1170.2 : 2021, may be considered as nearly comparable as possible to the definitions 'Life-line structures' and 'Industrial structures' of this standard. A comparison is attempted in Table 4.

Enhancement of cyclonic wind over non-cyclonic wind is signified by the cyclonic factor ($k_4$) in IS 875 (Part 3), whereas this enhancement factor is described by assigning different mean recurrence interval (MRI) values for the different importance levels of structure in Australian/New Zealand standard.

**A-2.2 Comparison with ASCE7-16 'Minimum design loads and associated criteria for buildings and other structures'**

The American standard follows the same design principles as the Australian/New Zealand standard, which categorizes buildings into four danger groups based on occupancy and use as given in Table 5. According to ASCE 7-16, normal structures are classified as risk category 2 and have 700 years RP, whereas post-disaster installations are classified as risk level 4 and have 3 000 years RP. Table 6 shows a comparison of wind speed for different risk categories in the United States.

**Table 4 Comparison of Present Study with Australian/New Zealand Standard**

(*Clause* A-2.1)

| Sl No. | As per Indian Standard with Threshold wind speed of 65 knot | As per AS/NZS 1170.2 : 2021 | |
|---|---|---|---|
| (1) | (2) | (3) | |
| i) | **a) Structures of Post-cyclone Importance** | | |
| | $k_4 = 1.28$ | Cyclone region, D | Cyclone region, C |
| | $x = 50 \times 1.28 = 64$ (L. F. = 1.5) | Importance level 3 | Importance level 3 |
| | $x = 78.08$ m/s (L. F. = 1.0) | L. F. = 1 | L. F. = 1 |
| | $N = 100, k_1 = 1.08$ | $F_D = 1.0$ | $F_D = 1.0$ |
| | $x = 1.08 \times 78.08 = 84.33$ m/s | $x = 85$ m/s | $x = 70$ m/s |
| ii) | **b) Industrial Buildings** | | |
| | $k_4 = 1.14$ | Cyclone region, D | Cyclone region, C |
| | $x = 50 \times 1.14 = 57.0$ (L. F. = 1.5) | Importance level 2 | Importance level 2 |
| | $x = 69.54$ m/s (L. F. = 1.0) | L. F. = 1 | L. F. = 1 |
| | $N = 100, k_1 = 1.08$ | $F_D = 1.0$ | $F_D = 1.0$ |
| | $x = 1.08 \times 69.54 = 75.103$ m/s | $x = 80$ m/s | $x = 66$ m/s |

## Table 5 Risk Categories as per ASCE 7-16

(*Clause* A-2.2)

| Sl No. | Use or Occupancy of Buildings and Structures | Risk Category |
|---|---|---|
| (1) | (2) | (3) |
| i) | Buildings and other structures that represent a low risk to human life in the event of failure. | I |
| ii) | All buildings and other structures except those listed in risk categories I, III, and IV. | II |
| iii) | a) Buildings and other structures, the failure of which could pose a substantial risk to human life. | III |
| | b) Buildings and other structures, not included in risk category IV, with potential to cause a substantial economic impact and/or mass disruption of day-to-day civilian life in the event of failure. | III |
| | c) Buildings and other structures not included in risk category IV (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, hazardous waste, or explosives) containing toxic or explosive substances where their quantity exceeds a threshold quantity established by the authority having jurisdiction and is sufficient to pose a threat to the public, if released. | III |
| iv) | a) Buildings and other structures designated as essential facilities. | IV |
| | b) Buildings and other structures, the failure of which could pose a substantial hazard to the community. | IV |
| | c) Buildings and other structures (including, but not limited to, facilities that manufacture, process, handle, store, use, or dispose of such substances as hazardous fuels, hazardous chemicals, or hazardous waste) containing sufficient quantities of highly toxic substances where the quantity exceeds a threshold quantity established by the authority having jurisdiction to be dangerous to the public if released and is sufficient to pose a threat to the public, if released. | IV |
| | d) Buildings and other structures required to maintain the functionality of other risk category IV structures. | IV |

## Table 6 Wind Speed for Different Risk Levels in the US (ASCE 7-16)

(*Clause* A-2.2)

| Sl No. | Parameters | Risk Category | | | |
|---|---|---|---|---|---|
| | | I | II | II | IV |
| (1) | (2) | (3) | (4) | (5) | (6) |
| i) | Return period | 300 | 700 | 1 700 | 3 000 |
| ii) | Interior region wind speed, mph | 85 to 107 | 90 to 114 | 95 to 112 | 100 to 122 |
| iii) | Coastal region wind speed, mph | 105 to 170 | 110 to 180 | 115 to 200 | 120 to 200 |

NOTE — 1 mph = 0.444 m/s.

Recommendations in this standard for Life-line structures and industrial structures are compared with ASCE 7-16, respectively in Table 7.

It is noteworthy from both examples that the order of cyclonic wind speeds is of the same as obtained in this standard. Similarly, the ratio of wind speed in the cyclonic zone to that in the normal zone (non-cyclonic) is also of the same order as $k_4$.

**Table 7 Comparison with ASCE 7-16**

(*Clause* A-2.2)

| **Sl No.** (1) | **As per Indian Standard with Threshold Wind Speed of 33.4 m/s (65 knot)** (2) | **As per ASCE 7-16** (3) |
|---|---|---|
| i) | **a) Structures of Post-cyclone Importance**<br>$k_4$ = 1.28<br>$x = 50 \times 1.28 = 64$ (L. F. = 1.5)<br>$x = 78.08$ m/s (L. F. = 1.0)<br>$N = 100, k_1 = 1.08$<br>$x = 1.08 \times 78.08 = 84.33$ m/s | Risk category – 3 Return period 1 700 years<br>$x = 200$ mph<br>$x = 89$ m/s |
| ii) | **b) Industrial Buildings**<br>$k_4 = 1.15$<br>$x = 50 \times 1.14 = 57.0$ (L. F. = 1.5)<br>$x = 69.54$ m/s (L. F. = 1.0)<br>$N = 100, k_1 = 1.08$<br>$x = 1.08 \times 69.54 = 75.103$ m/s | Risk category – 2<br>Return period 700 years<br>$x = 180$ mph<br>$x = 80.5$ m/s |

## ANNEX B

(*Clause* 5.3)

## GUMBEL DISTRIBUTION PARAMETERS FOR CYCLONIC WIND SPEED

**B-1** Distribution parameter for Gumbel distribution such as standard deviation and mean with threshold speed 33.4 m/s (65 knot) is given in Table 8.

**Table 8 Distribution Parameter for Gumbel Distribution**

(*Clause* B-1)

| **Type of Distribution** (1) | **Curvature Parameter** ($\tau$) (2) | **Standard Deviation** ($\sigma$) m/s (3) | **Mean** (m) m/s (4) |
|---|---|---|---|
| Gumbel | 0 | 8.371 6 | 43.338 5 |

## ANNEX C

(*Foreword*)

## COMMITTEE COMPOSITION

Cyclone Resistant Structures Sectional Committee, CED 57

| *Organization* | *Representative(s)* |
|---|---|
| In Personal Capacity (*B-03-3, Raheja Atlantis, National Highway 08, Sector 31 - 32A, Gurugram*) | DR PREM KRISHNA (***Chairperson***) |
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(*Continued from second cover*)

c) Simiu E., Scanlan R. H. 2000 ‘Winds Effects on Structures: Fundamentals and Applications to Design’ Wiley Publication
d) Venkateswarlu B., Arumugam M. and Arunachalam S. 1985 ‘Risk Analysis of Cyclonic Wind Data’ Proceedding of national workshop on tall reinforced concrete chimneys 25-27 April 1985, New Delhi.
e) Venkateswarlu B., Arunachalam S. and Shanmugasundaram J. 1986 ‘Probability Factor for Wind Speed in India.’ *Journal of Structural Engineering* 13(1) : 1 – 9.

The composition of the Committee responsible for the formulation of this standard is given in Annex C.

This standard contributes to the United Nations' Sustainable Development Goal 9 ‘Industry, innovation and infrastructure’ towards building resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

For the purpose of deciding whether a particular requirement of this standard is complied with the final value, observed or calculated, expressing the result of a test or analysis shall be rounded off in accordance with IS 2 : 2022 ‘Rules for rounding off numerical values (*second revision*)’. The number of significant places retained in the rounded off value should be the same as that of the specified value in this standard.

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This Indian Standard has been developed from Doc No.: CED 57 (21667).

## Amendments Issued Since Publication

| Amend No. | Date of Issue | Text Affected |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

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Published by BIS, New Delhi